APPENDIX 1

PARTIAL CRYSTAL CONTROL

1. There are three available methods of achieving a high degree of frequency stability in a transmitter. These are:-

(i) Crystal Control. This is a conventional method in modern W/T sets, but it suffers from the grave disadvantage of inflexibility of the output frequency: even if a large number of interchangeable crystals is used, and this is undesirable in itself, only spot frequencies can be transmitted. (Examples: Original Type 89, Type 65).

(ii) Master Control. A high degree of frequency stability can be attained by a very careful design of a master oscillator circuit, using specially designed components of extra high quality. This may involve a temperature oven, or individual temperature compensation of components in the M.O. circuit or both. (Example: American TBL).

(iii) Partial Crystal Control (P.C.C.) This has been introduced to meet the requirements of high frequency stability, and at the same time give a continuously tunable range, without using components or circuits of special design. (Example: Type 57 Frequency Control Panel, Type 601 series).

2. The principle is that a crystal oscillator of fixed frequency or one of its harmonics, controls a large proportion of the output frequency; the rest being covered by a comparatively crude self-excited oscillator of a variable and tunable frequency. Only one crystal is required in later designs.

Theory.

3. If a frequency q is amplitude modulated by another frequency v, the resulting waveform may be considered to consist of the following three frequencies:-

q - v (lower sideband frequency)
q (carrier frequency)
q + v (upper sideband frequency)

In the P.C.C. system the carrier frequency q is a suitable harmonic of a quartz crystal, while the modulating frequency v is supplied by a variable oscillator. v is considerably lower than q. The two frequencies are fed into a balanced mixer: q at the grids and v at the screen grids, so that q is modulated by v (see Admiralty Handbook of Wireless Telegraphy (1938) Volume 2 Section N18). The carrier q is suppressed, and it is possible to select the upper (or the lower) sideband in the anode tuned circuit, the other sideband then being very considerably attenuated.

In the Type 601 series, the sideband q + v is the one always selected. The two frequencies may therefore be said to be added.

4. Assuming that the frequency q is completely stable, then if v is altered by a number of c/s the resultant frequency will alter by the same amount. For a given frequency tolerance, therefore, the frequency v is permitted a much greater percentage of instability than a normal master oscillator, as the following numerical example makes clear:-

q = 5,000 kc/s
v = 500 kc/s
resultant (q + v) = 5,500 kc/s

If the resultant frequency tolerance permitted is 500 c/s, the percentage stability of v must be $\frac{500 \text{ c/s}}{500 \text{ kc/s}} \times 100 = .1\%$. But if the output were produced directly by a variable oscillator, its percentage stability must be

$$\frac{500 \text{ c/s}}{5{,}500 \text{ kc/s}} \times 100 = .011\%$$

This is another way of saying that a high proportion of the output frequency is controlled by the crystal harmonic. In the above example, the percentage frequency stability of the transmitter is better than that of the variable oscillator alone by a factor which approaches 10. Although the overall stability is not quite as high as that of a conventional crystal oscillator, it has been found to lie well within the required limits for working a crystal controlled receiver on an aircraft, which is the most difficult condition likely to be encountered.

5. In its application to the Type 601 series of transmitters, P.C.C. is used on three H/F ranges of Transmitter 5AB. "q + v" lies between 3 and 6 Mc/s, continuously tunable, and this is multiplied as necessary by later stages to provide a total coverage of 3 to 24 Mc/s. Since the required degree of stabilisation in terms of cycles/second can more easily be achieved at lower frequencies, P.C.C. is not used for the ranges 1.5 to 3 Mc/s in Transmitter 5AB; nor is it used in Transmitter 4AD, output 200 - 500 kc/s.

6. The disadvantage of P.C.C. lies in certain effects of spurious frequency production. By careful design and choice of the relative values of q and v, these effects can be considerably reduced. The spurious frequencies lie close to the channel frequency being used, and the effects are:-

(i) W/T. Weak signals near the working frequency can be detected, on certain frequencies.

(ii) R.T. Weak signals resembling adjacent channel interference can be detected on certain frequencies: these are more pronounced when the receiver is slightly off tune.

7. The spurious frequencies are in general produced by beating between the crystal and variable oscillator frequencies, and their harmonics. The beat frequency produces sidebands situated near the main channel frequency on either side of it, and separated from it by the value of the beat frequency or its multiples. When the beat frequency is sufficiently high the spurious sidebands become strongly attenuated as a result of the combined selectivity of all the tuned circuits involved.

The spurious sidebands are more pronounced after multiplication of the mixed frequency has taken place, i.e. nearer the 24 Mc/s end of the frequency range. They are also more pronounced at certain spots of the frequency range, particularly in Transmitter 5AB, when the V.O. is near 500, 625, 666.7, 750, 833.3, or 1,000 kc/s. Numerical examples should help to make the production of spurious frequencies clear:-

(i)
$$\begin{aligned} q &= 2{,}500 \text{ kc/s} \\ v &= 833.6 \text{ kc/s} \\ q + v &= 3333.6 \text{ kc/s} \\ 4v &= 3334.4 \text{ kc/s} \end{aligned}$$

The fourth harmonic, 4v, beats with q + v to produce an audio beat note of 800 c/s. The effect on the receiver is similar to the effect of a weak interfering station, and it will therefore disturb wanted R.T. Careful tuning of the receiver will reduce the disturbance to some extent, but it is not possible to tune away from the spurious sideband as it is less than 1 kc/s. removed from the channel frequency.

7. (ii) q = 2500 kc/s
v = 825 kc/s
q + v = 3325 kc/s
here 4v = 3,300 kc/s.

The beat frequency in this case is above the limit of audible frequency (25,000 c/s), and will not therefore disturb R.T. But it will produce weak signals separated from the main channel by 25 kc/s, and it is possible to tune in to one of these in error, on W/T. Examples (i) and (ii) show the two possible effects; both effects are more pronounced when receiving on local receivers. Care should then be taken that the receiver R.F. gain control is turned down as far as possible, without unduly reducing signal/noise ratio.

8. The production of harmonics of the working frequency, as opposed to the spurious frequencies described above, is not a special feature of P.C.C. and therefore presents the same problem as it does in other types of transmitter.

Advantages

9. The advantages of P.C.C. may be summed up as follows:-

(i) Using existing patternised components a much higher degree of stability is possible than with conventional master oscillator control. This includes all effects influencing frequency stability such as mains voltage, shocks, vibration, thermal effects, keying, and valves.

(ii) The variable oscillator dial covers a much smaller range of frequencies thus making reading and calibration of the dial simpler.

(iii) Only one crystal is required, and a continuously tunable range is available. No temperature oven is required as stability falls within present required limits without one.

(iv) Calibrations of the variable oscillator can be checked at selected spots against the crystal, without referring to external wave-meter.

Disadvantages.

10. The main disadvantage of P.C.C. is the production of spurious frequencies in the neighbourhood of the wanted frequency. These effects occur only within certain narrow bands and have been reduced to practically harmless values.